PENNSTATE

Modeling of Electromagnetic Signatures of Massive Black Hole Binaries

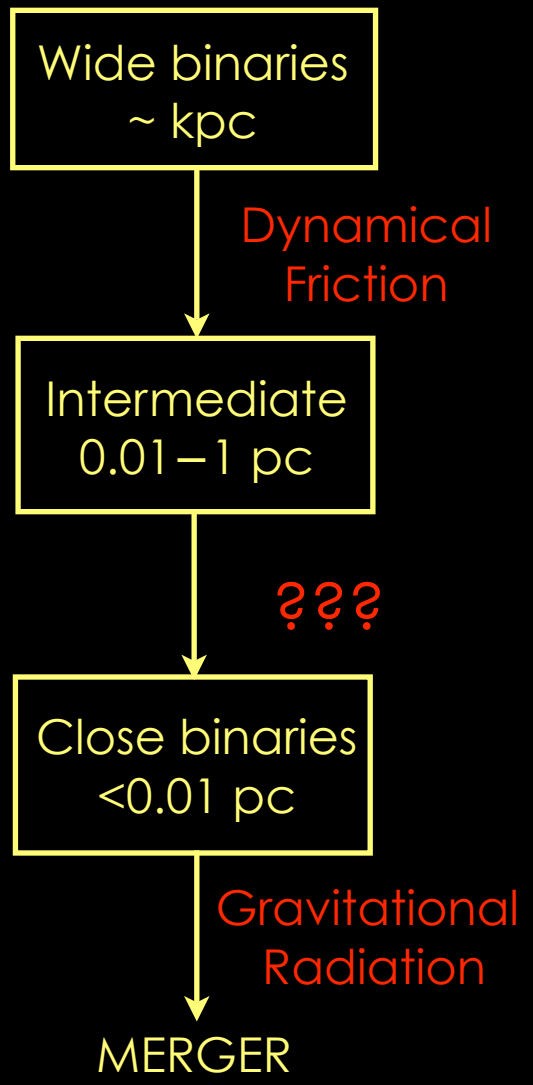
Tamara Bogdanovic, Britton Smith, Steinn Sigurdsson, and Michael Eracleous

Department of Astronomy & Astrophysics

Center for Gravitational Wave Physics

The Project

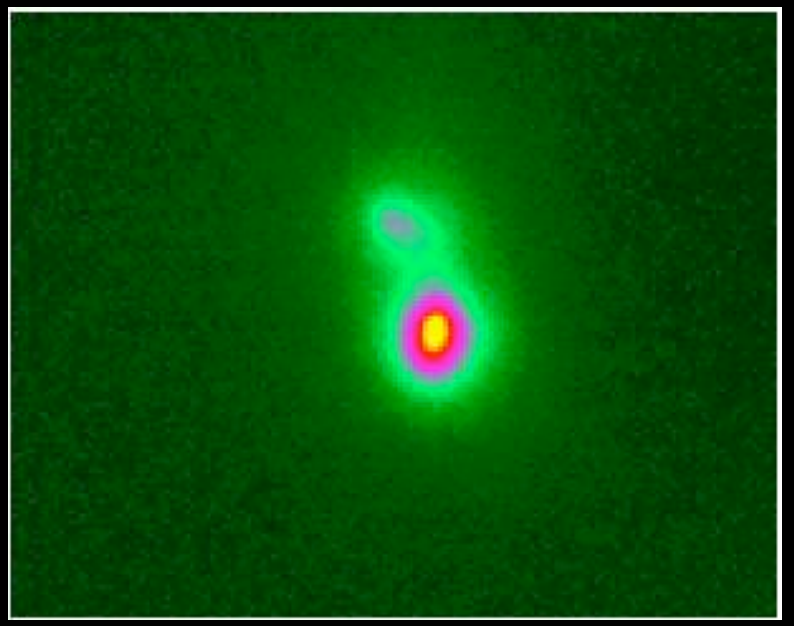
- We model massive black hole binaries (MBHBs) with associated gas component
- Sub-parsec, gravitationally bound, intermediate phase binaries
- Goal: Model X-ray and optical observational signatures of MBHBs



PENNSTATE

The Motivation

- Hard to find
  - 1pc @ 100Mpc ≈ 2mas
- Observational evidence
  - NGC 6240, OJ 287
- How many are there?
- What are their merger rates? (LISA)
- Orbital parameters ? (LISA)
- How do they evolve through the last parsec ?



NGC 6240

PENNSTATE

Calculations

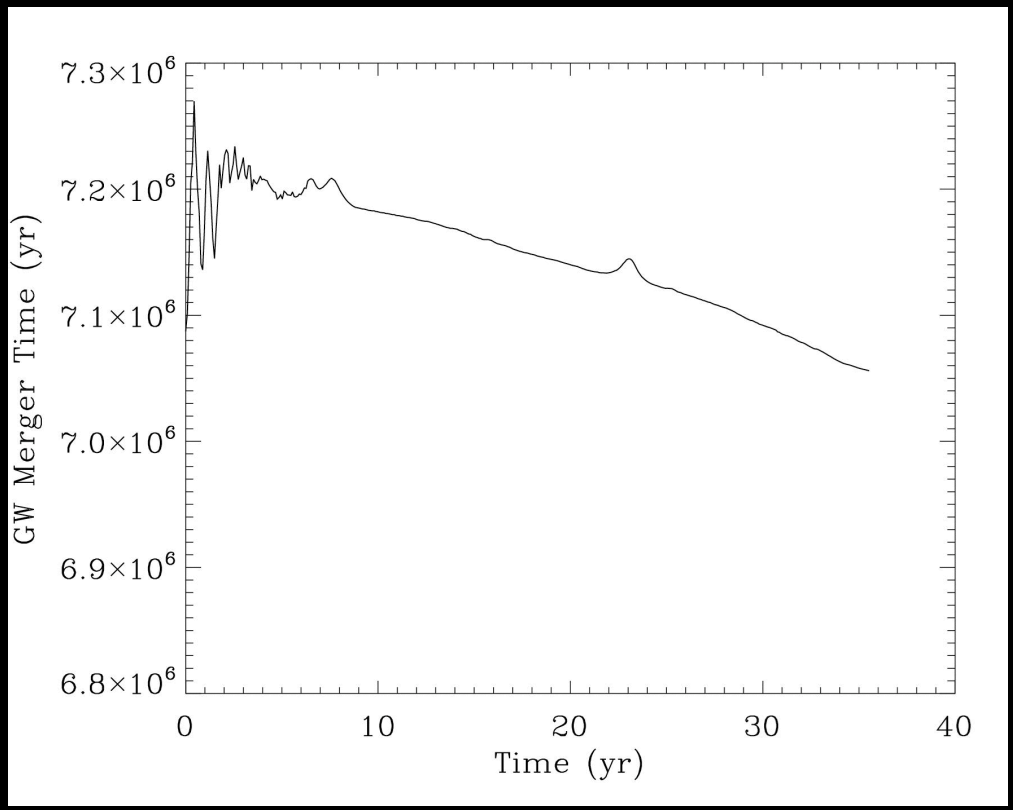
- Hydrodynamical simulations
- Gadget (Springel, Yoshida, & White '01, Springel '05)
  - N-body + SPH
- Relativistic MBHB system
- Gas heating & cooling and radiative transfer
- X-ray and Hα light curves and Hα emission line profiles

Relativistic Binary

- Pseudo-Newtonian potential (Paczynksy & Wiita '80; PW)

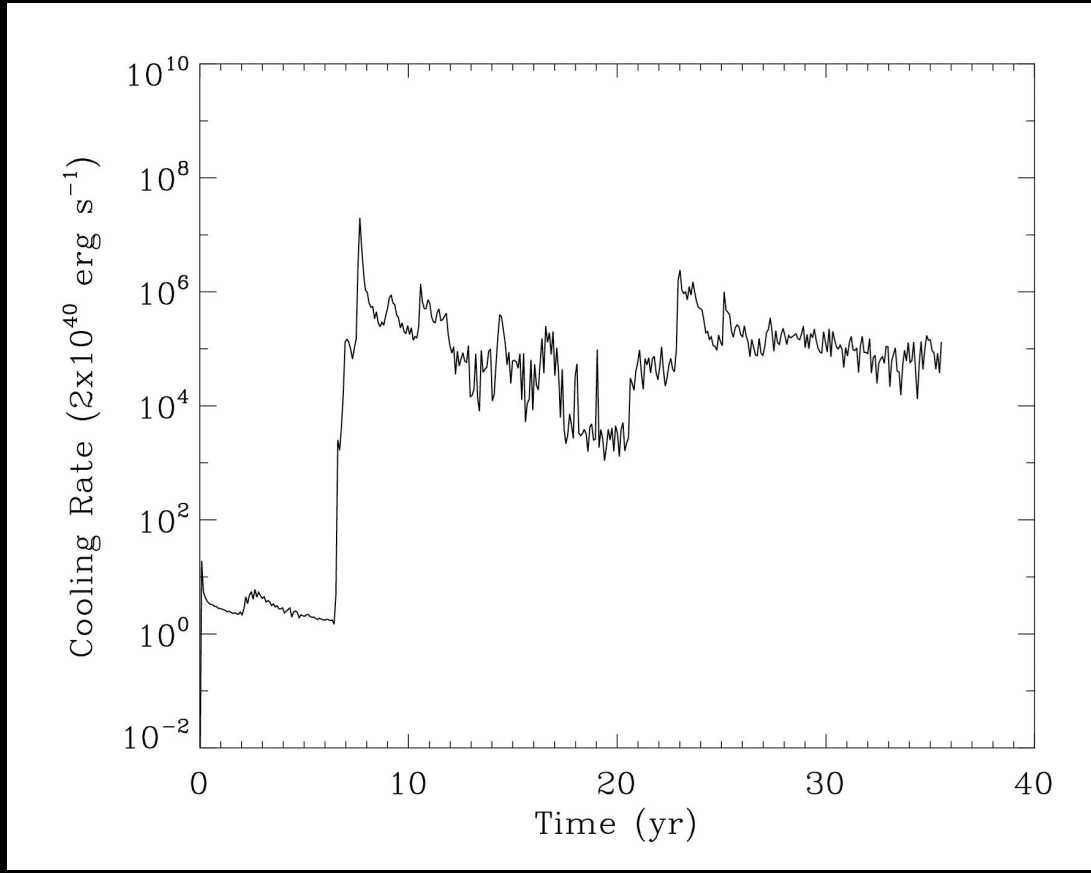
$$\phi = -\frac{GM}{r - r_s}$$

- BH orbits in PW-potetnial
- Interactions with the gas
- Emission of gravitational radiation (Landau & Lifshitz '75)

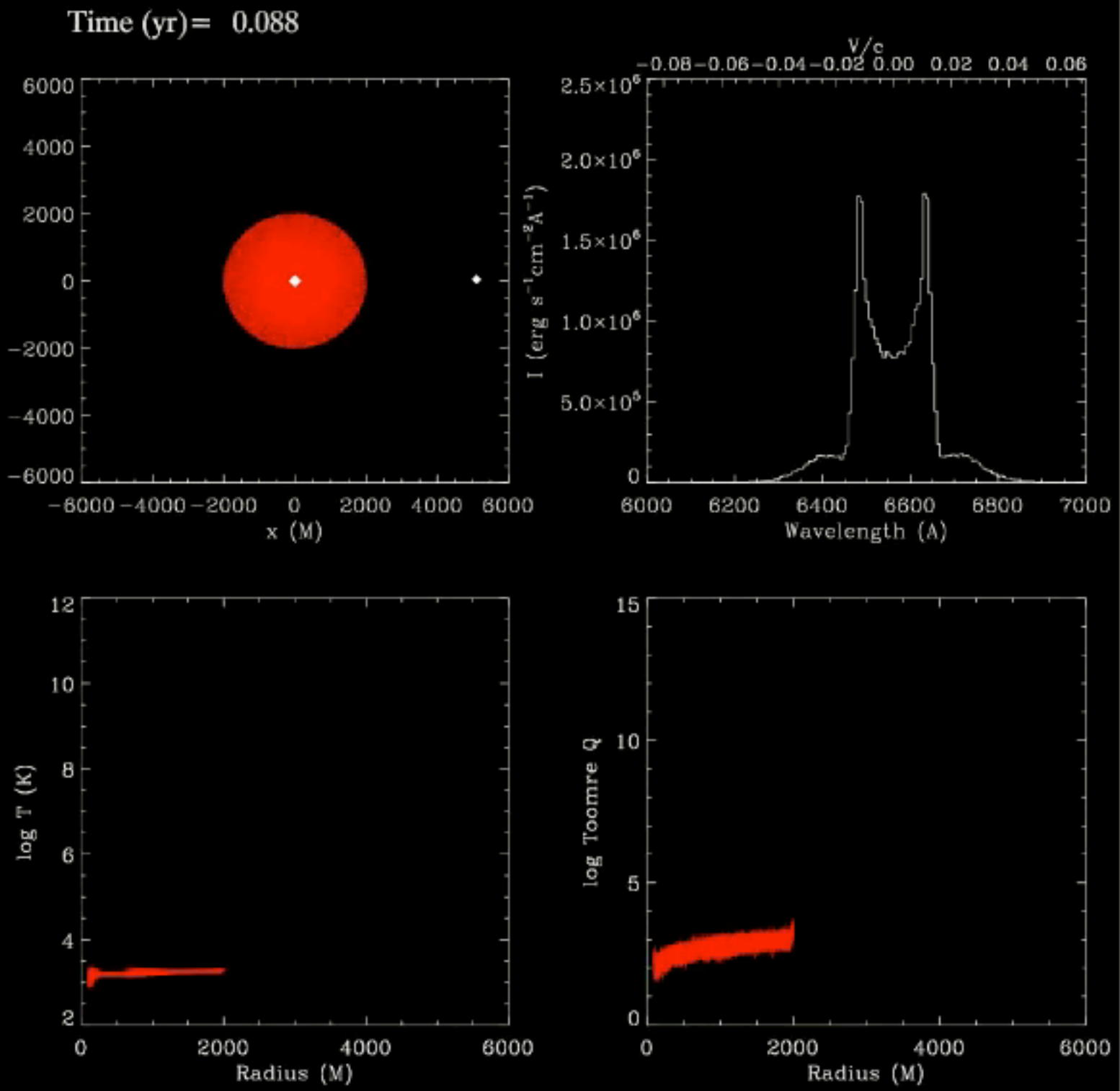


Heating & Cooling of Gas

- Gas heated by shocks and illuminated by radiation
- Black-Body gas
- H-He gas
- Solar metallicity ⇒
- Radiative transfer calculation with CLOUDY (Ferland et al. 98)



PENNSTATE

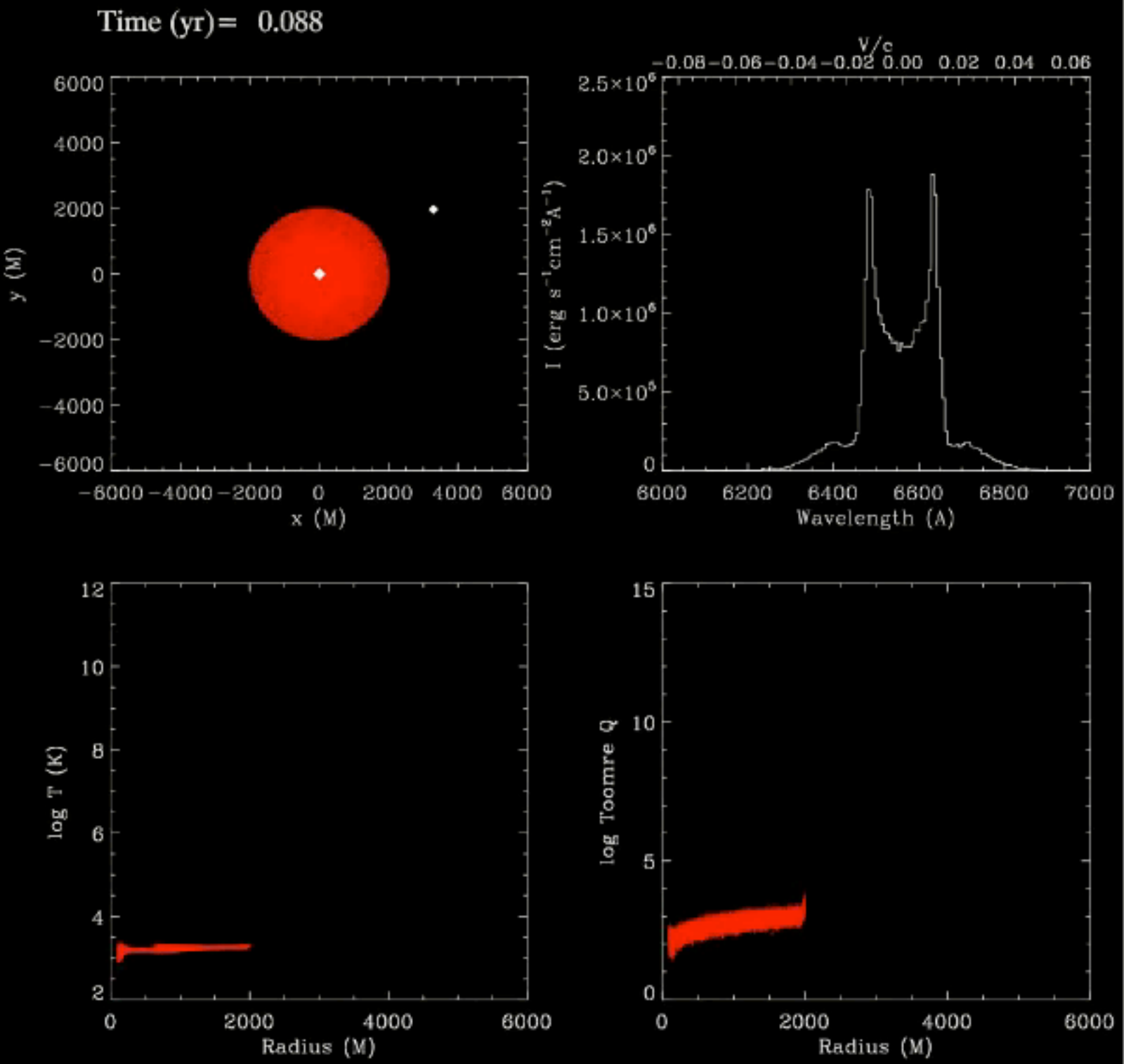


Co-rotating binary

- Co-planar
- $a \approx 3000$, $e \approx 0.7$
- $P \approx 16$ yrs
- BH1: $10^8\ M_\odot$
- BH2: $10^7\ M_\odot$
- Gas: $10^4\ M_\odot$

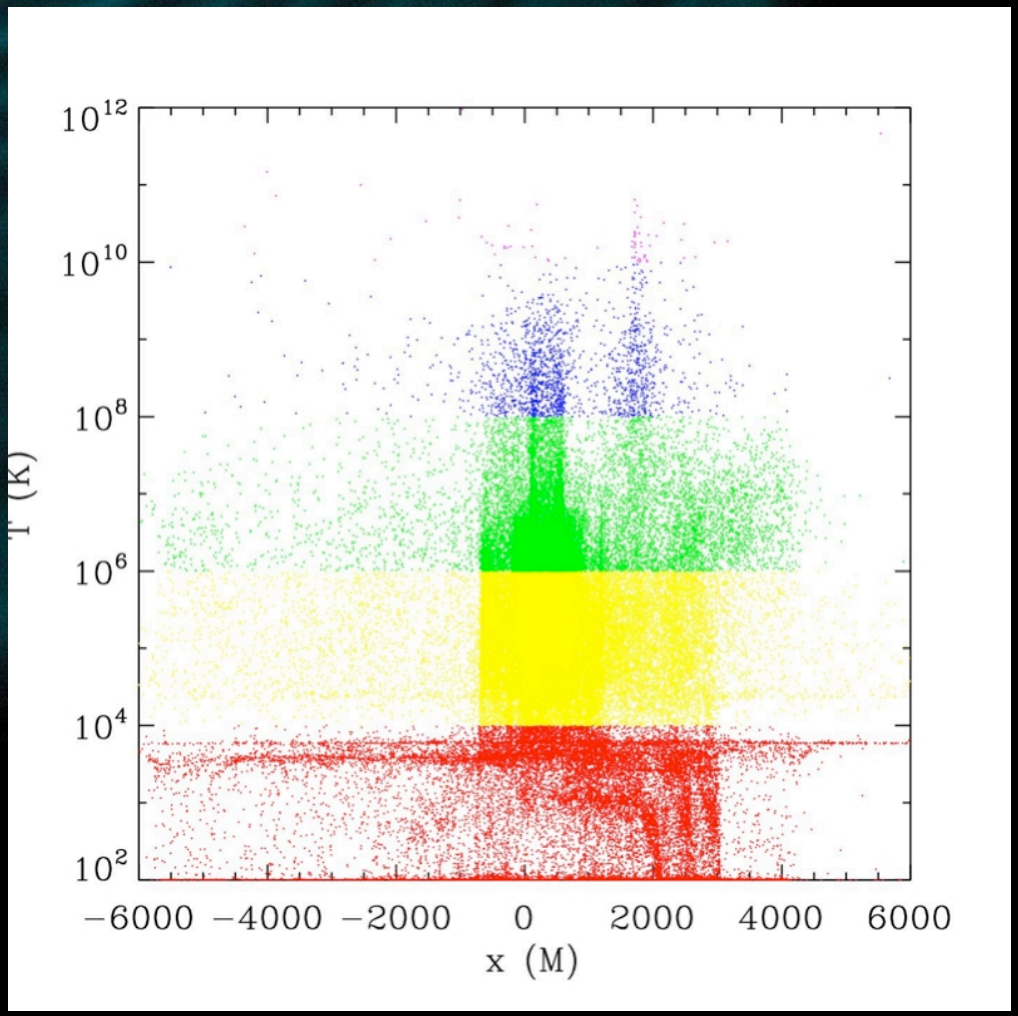
PENNSTATE

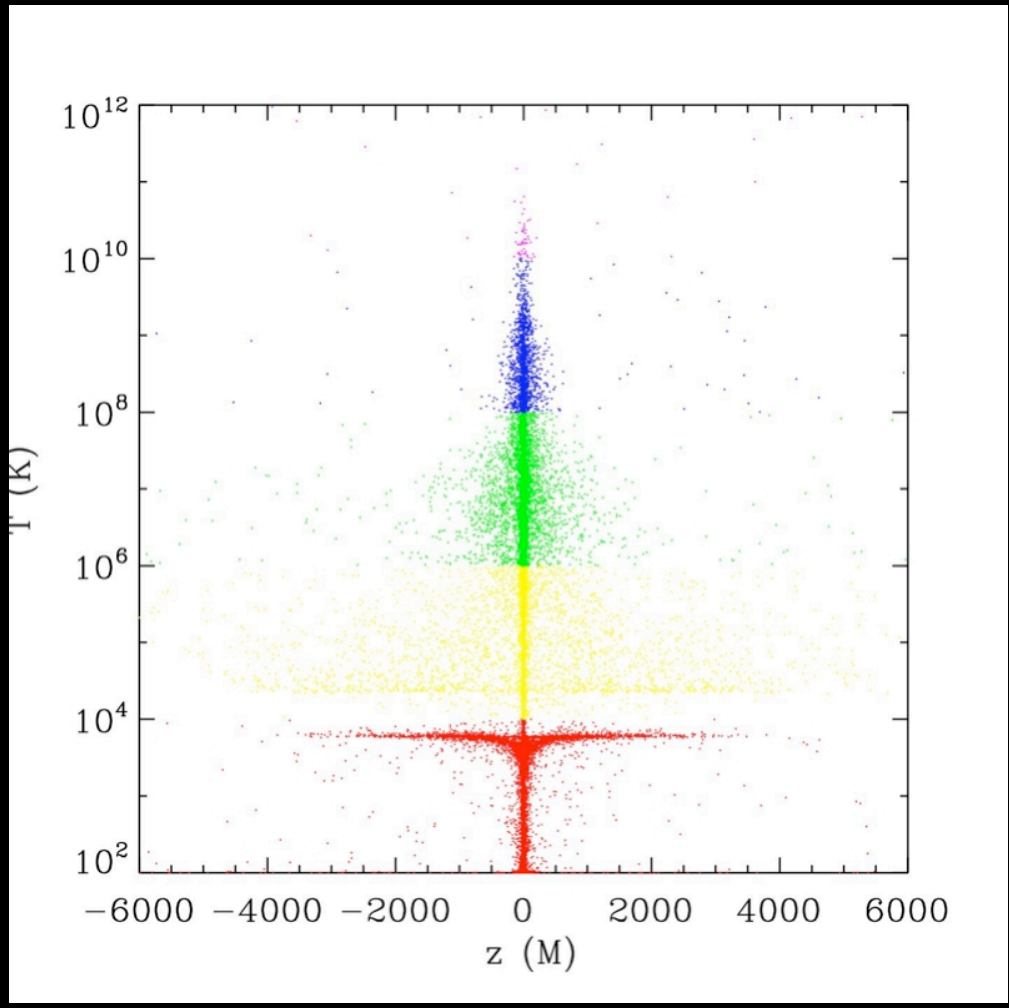
Counter-rotating binary



- Co-planar
- a ≈ 3000, e ≈ 0.7
- P ≈ 16 yrs
- BH1: 10^8 $M_\odot$
- BH2: 10^7 $M_\odot$
- Gas: 10^4 $M_\odot$

Temperature Distribution

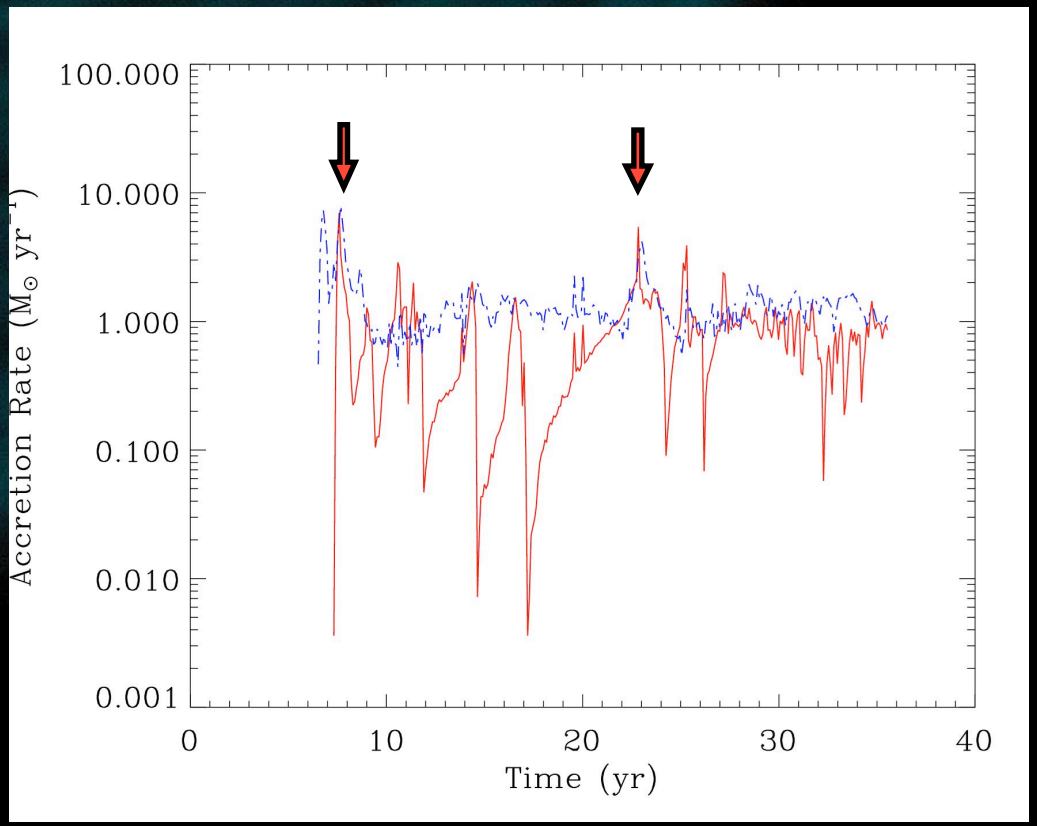




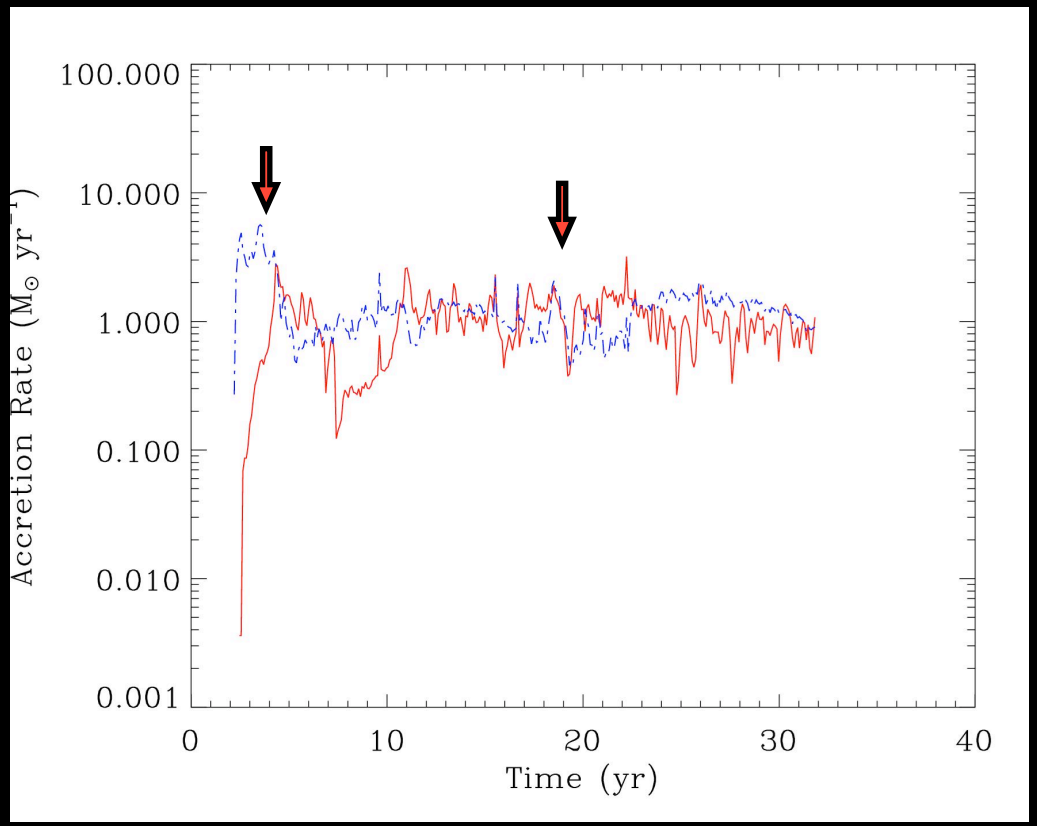
Accretion Rates

- Emission sources powered by accretion

  ($1 M_\odot/yr \sim 10^{43}$ erg/s UV/X-ray)

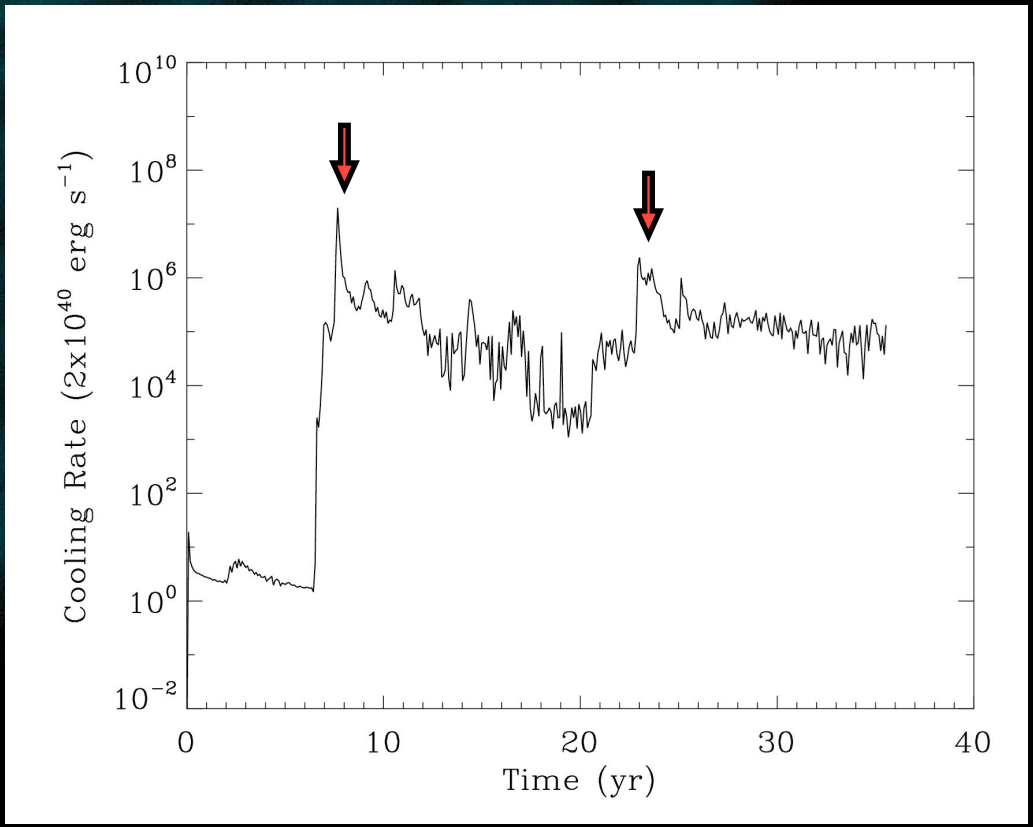


Co-rotating

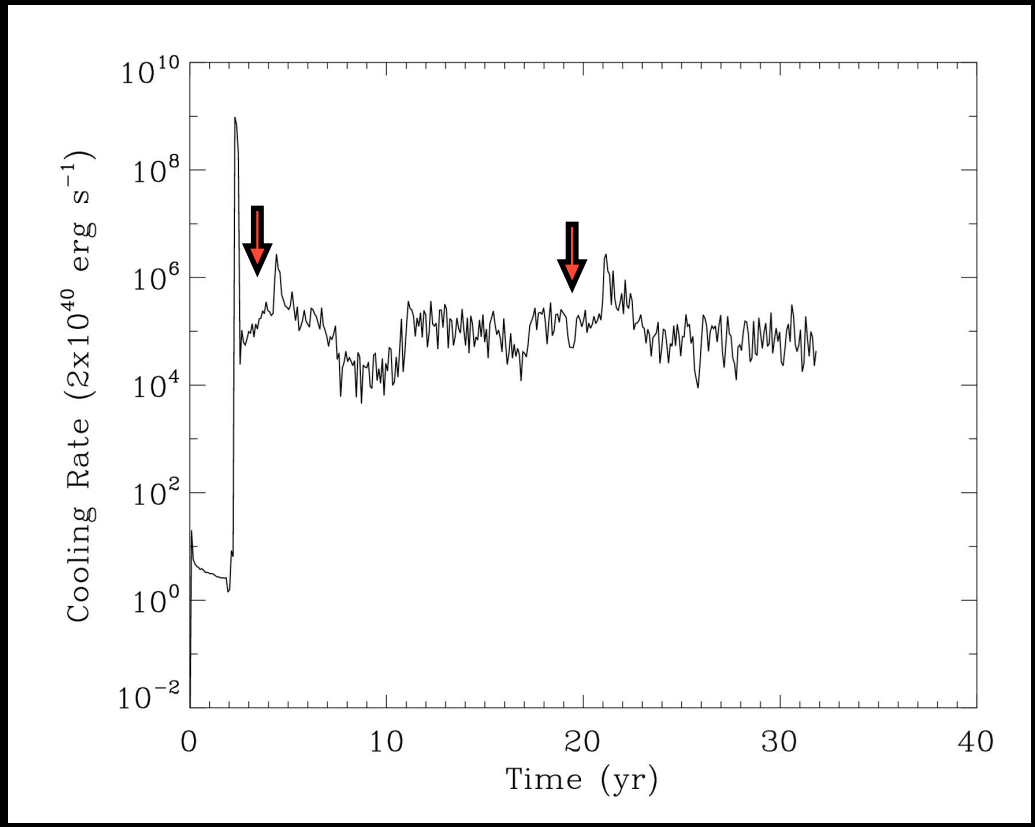


Counter-rotating

Bolometric Light Curves



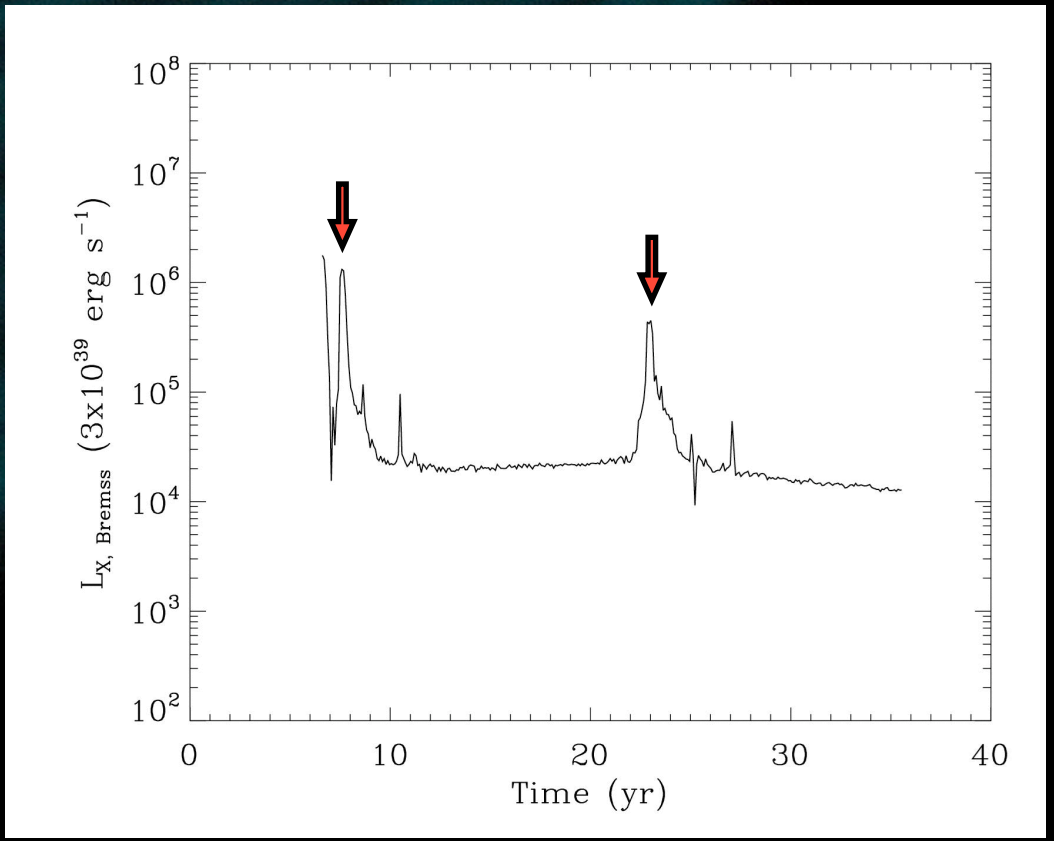
Co-rotating



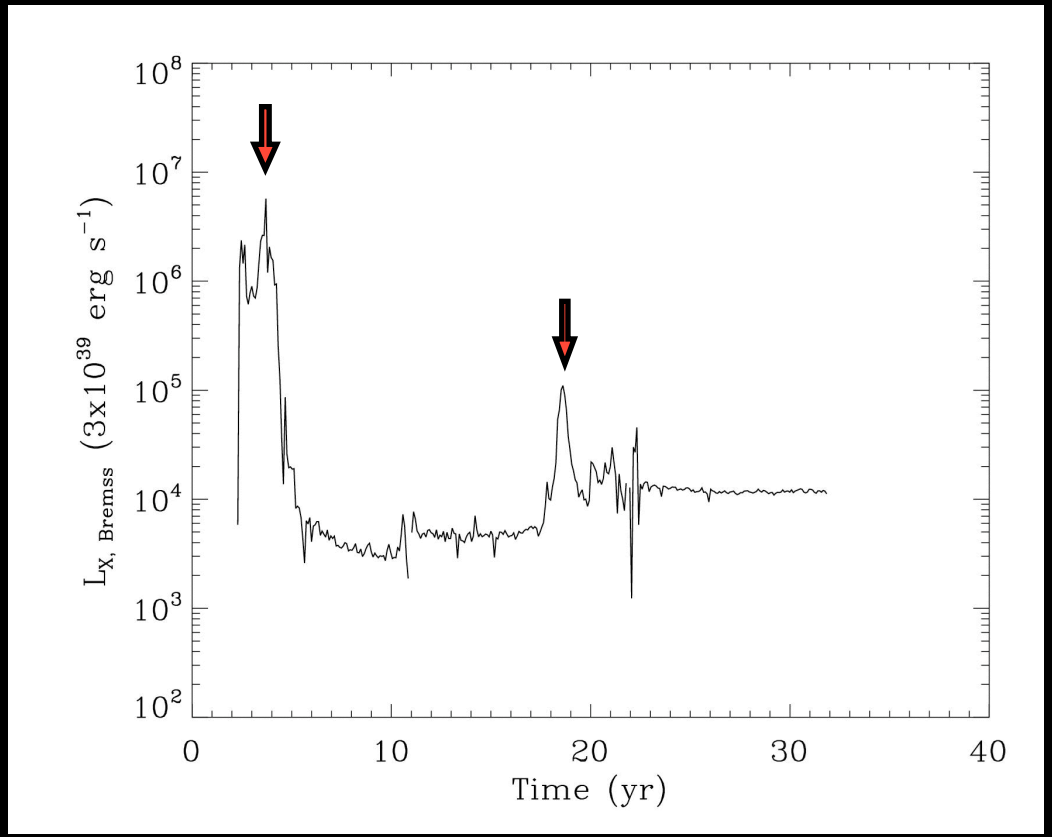
Counter-rotating

X-ray Light Curves

- Bremsstrahlung emission from gas, $T > 10^7$ K

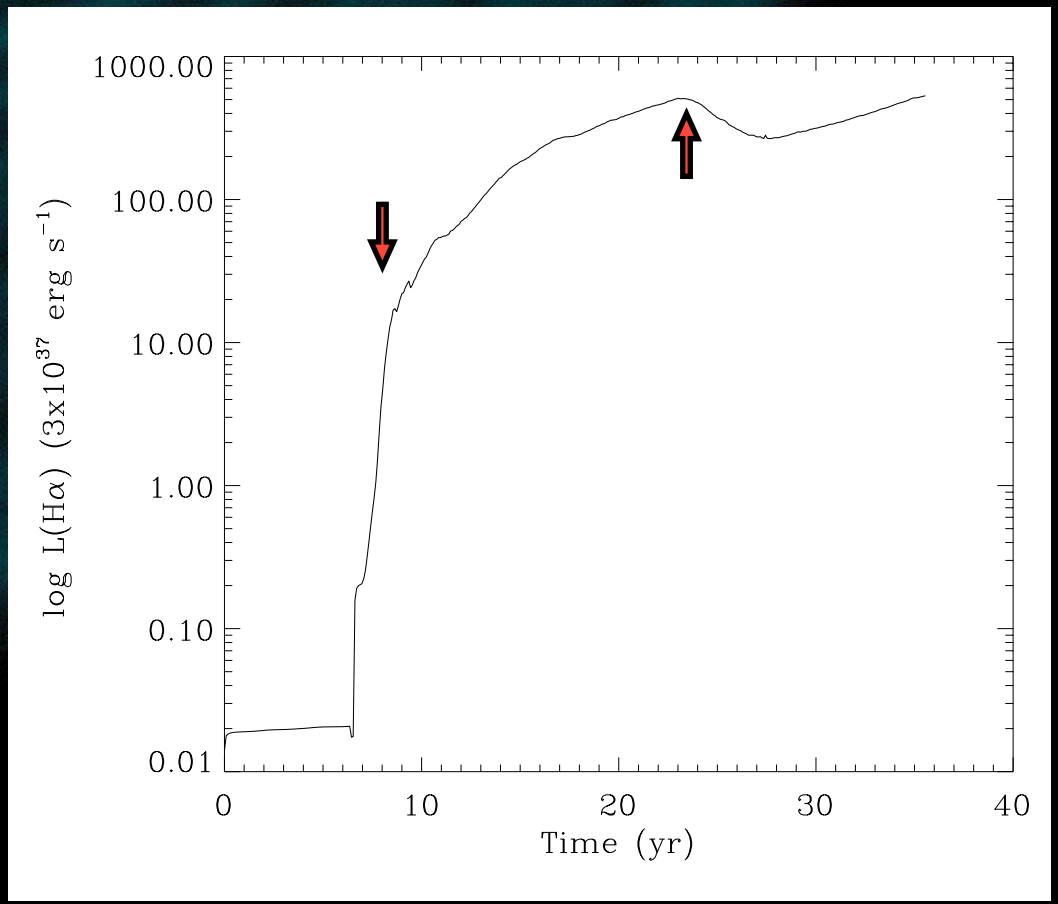


Co-rotating

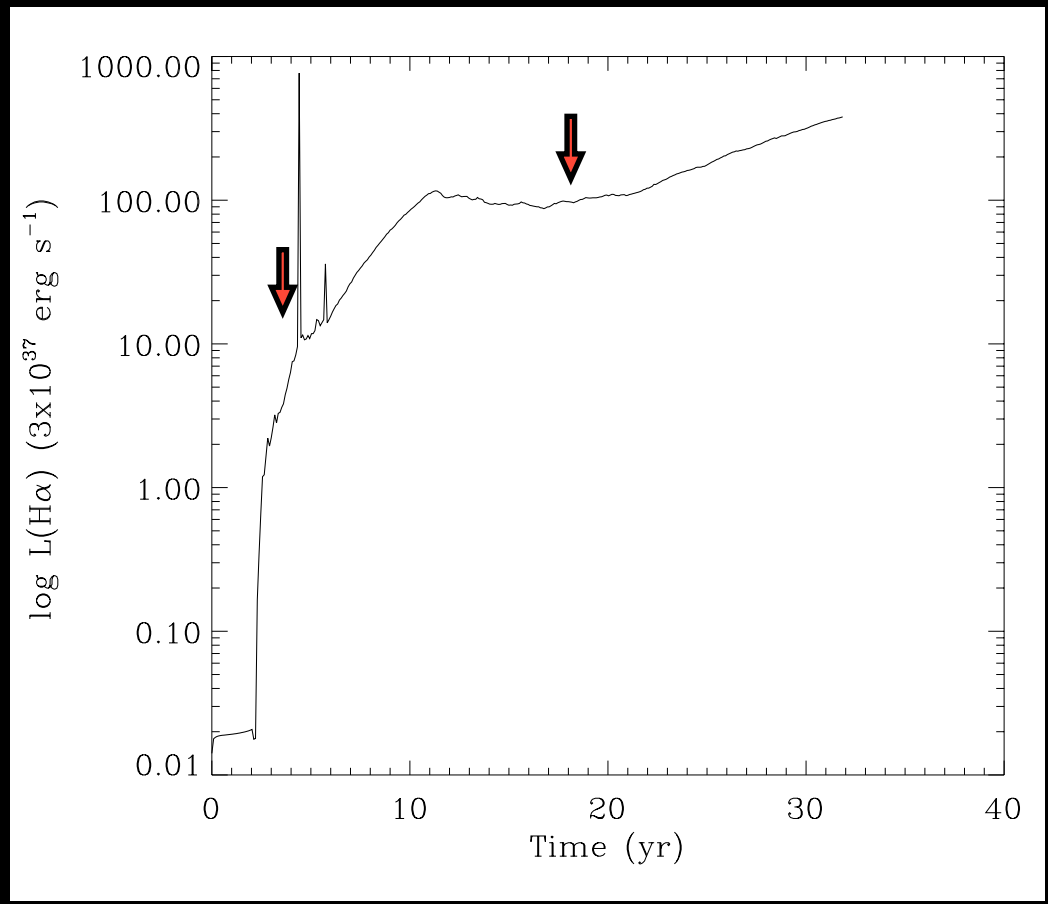


Counter-rotating

Hα Light Curves



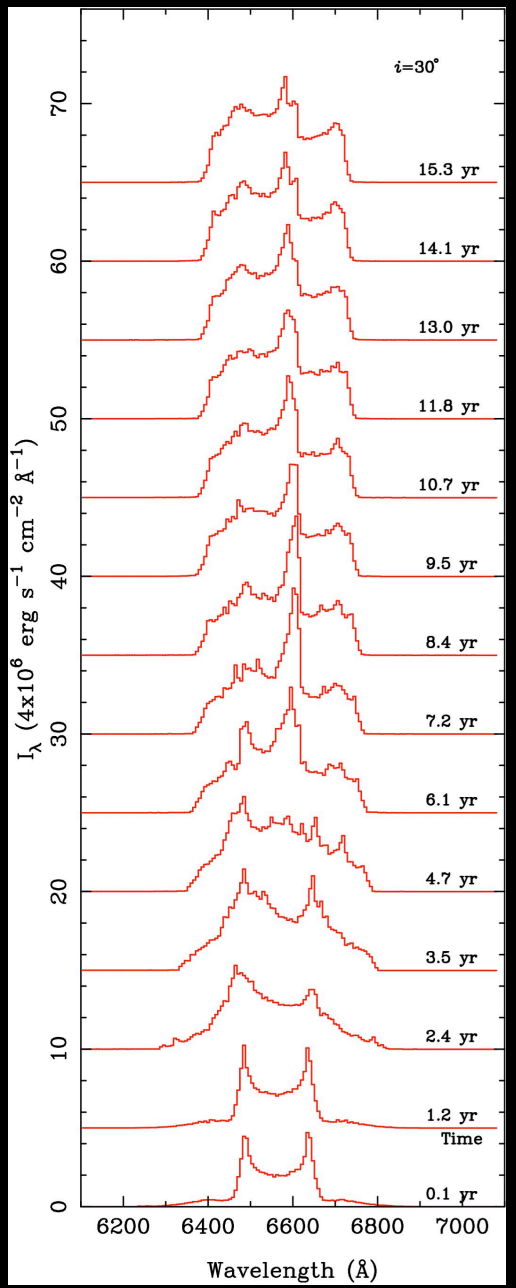
Co-rotating

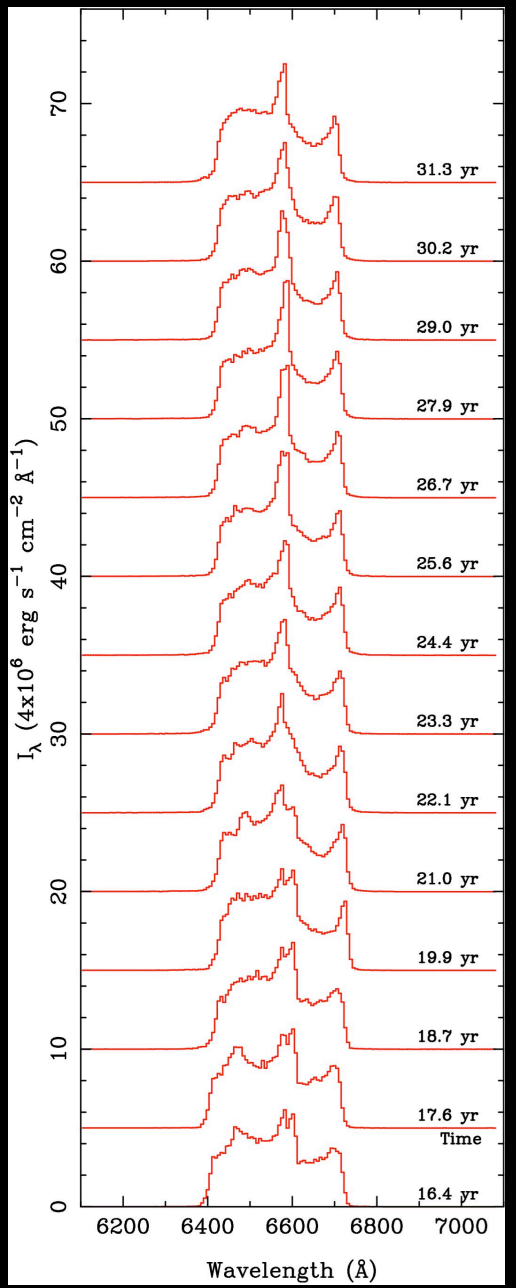


Counter-rotating

Hα Emission-Line Profiles

- Irregular & variable
- Can be used as screening criterion on existing archival data (SDSS)
- Could constrain period and mass ratio of the binary

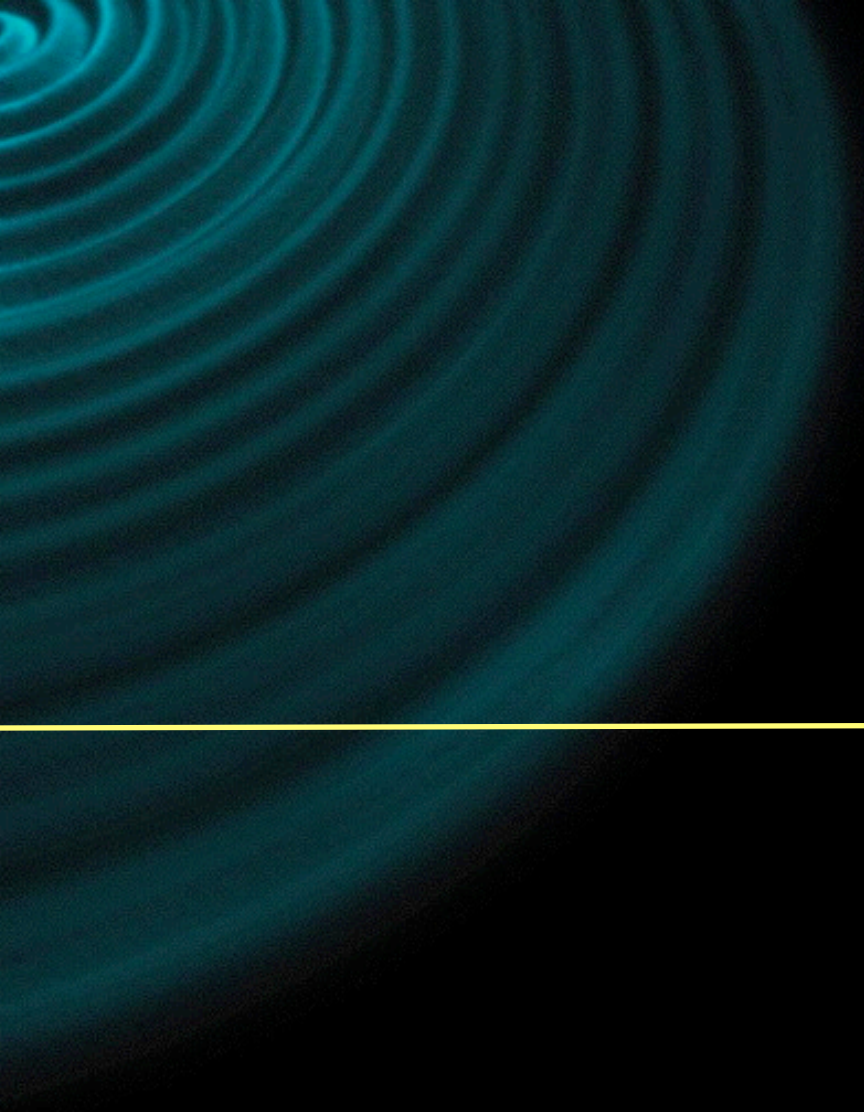




PENNSTATE

Conclusions

- We model observational signatures of MBHBs
- Also, evolution of T, Q , Γ, Λ, a, e in time.
- Simulations confirm that light curves exhibit periodicity.
- Hα profiles can be used to identify binary candidates, and put constrains on orbital parameters.
- Binary orbital evolution dominated by interactions with gas.
- If observed, signatures of binaries could constrain evolution of MBHBs through the last parsec and their merger rates.

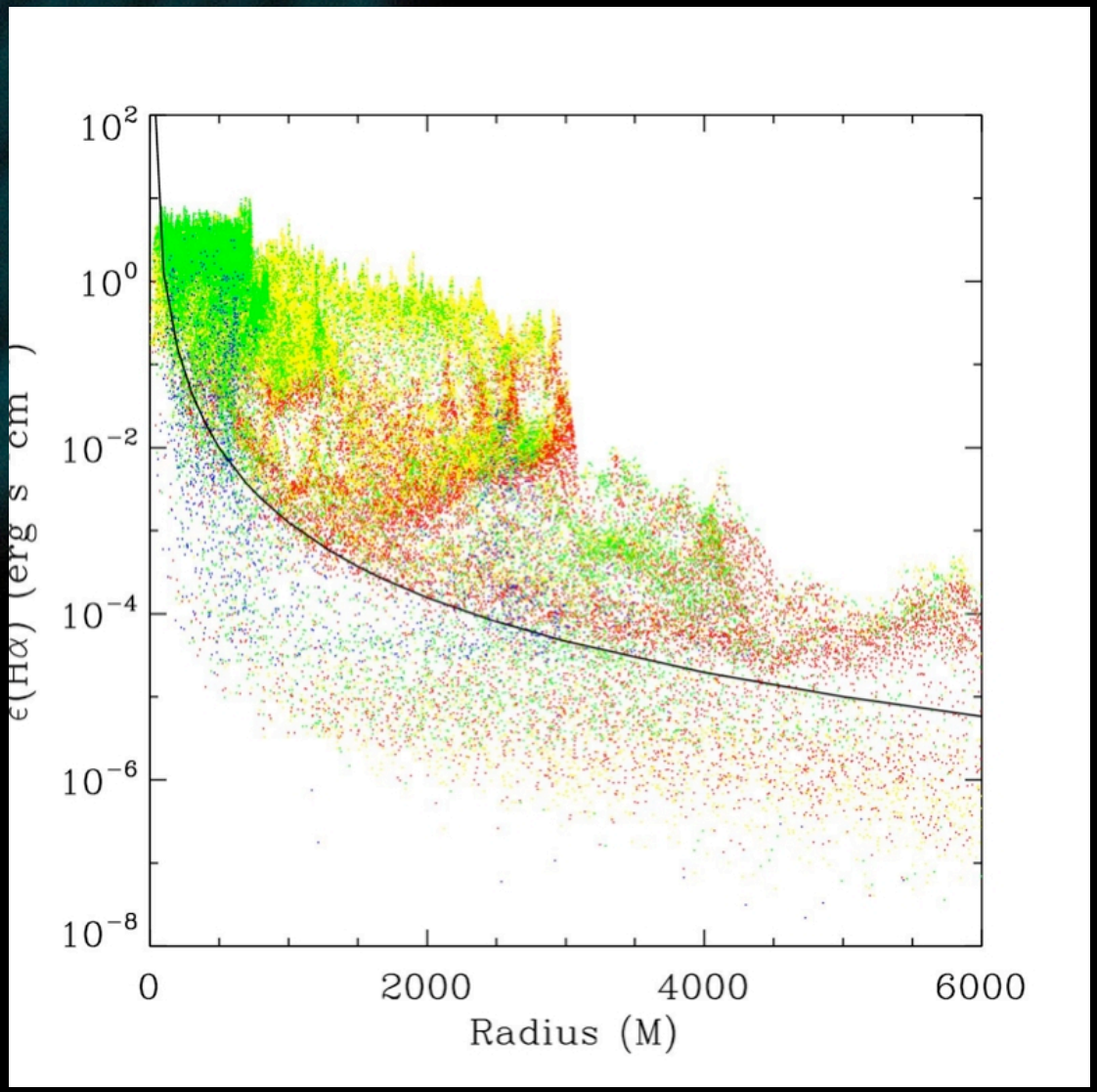


PENNSTATE

1855

The End

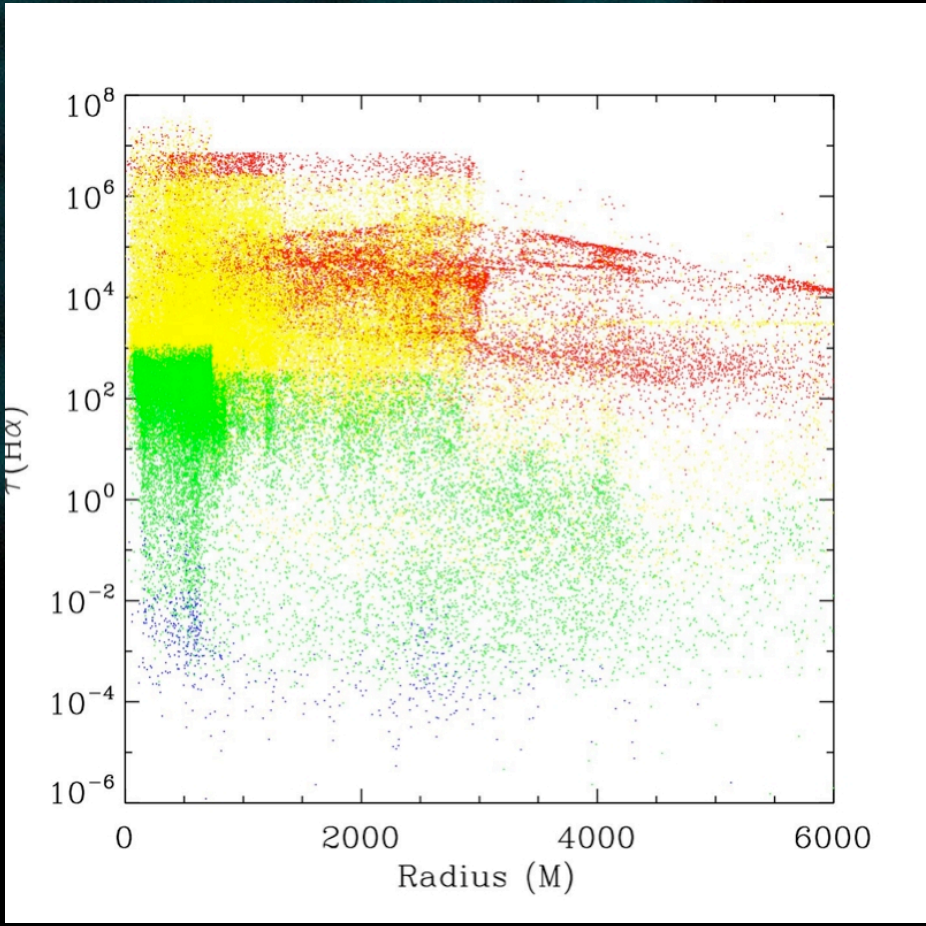
Emissivity Distribution



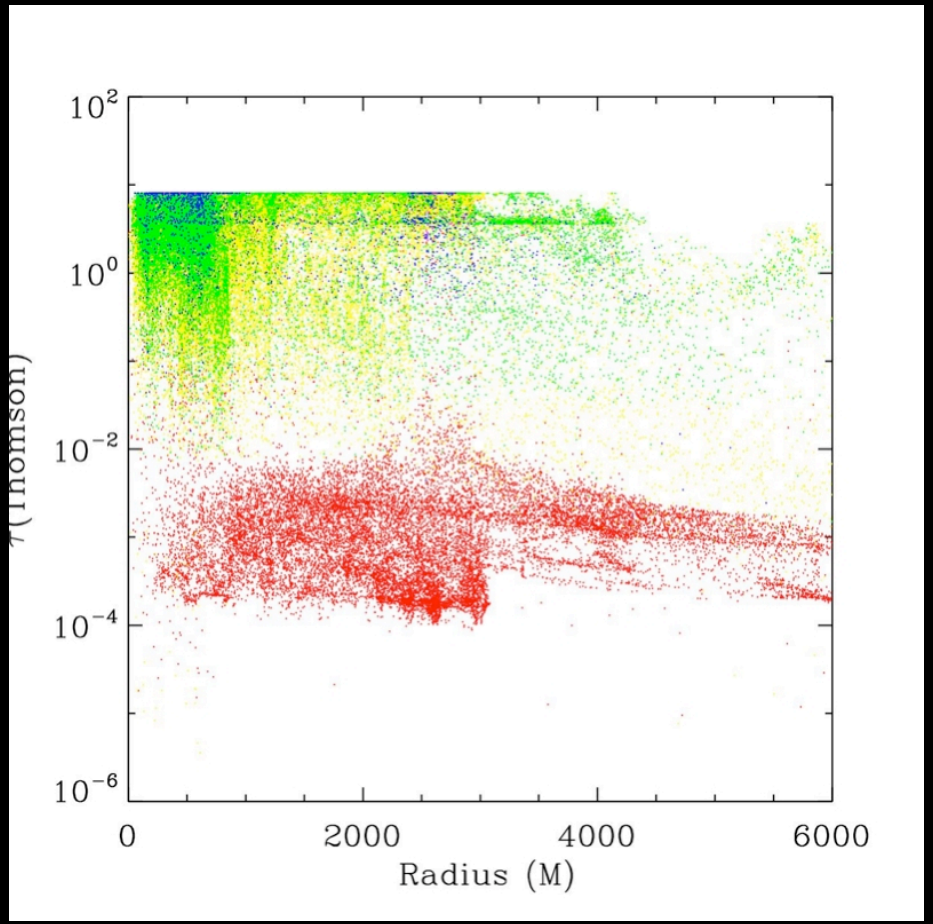
$T<10^4$ K $10^4<T<10^6$ K $10^6<T<10^8$ K $10^8<T<10^{10}$ K

Optical depths

τ(Hα)

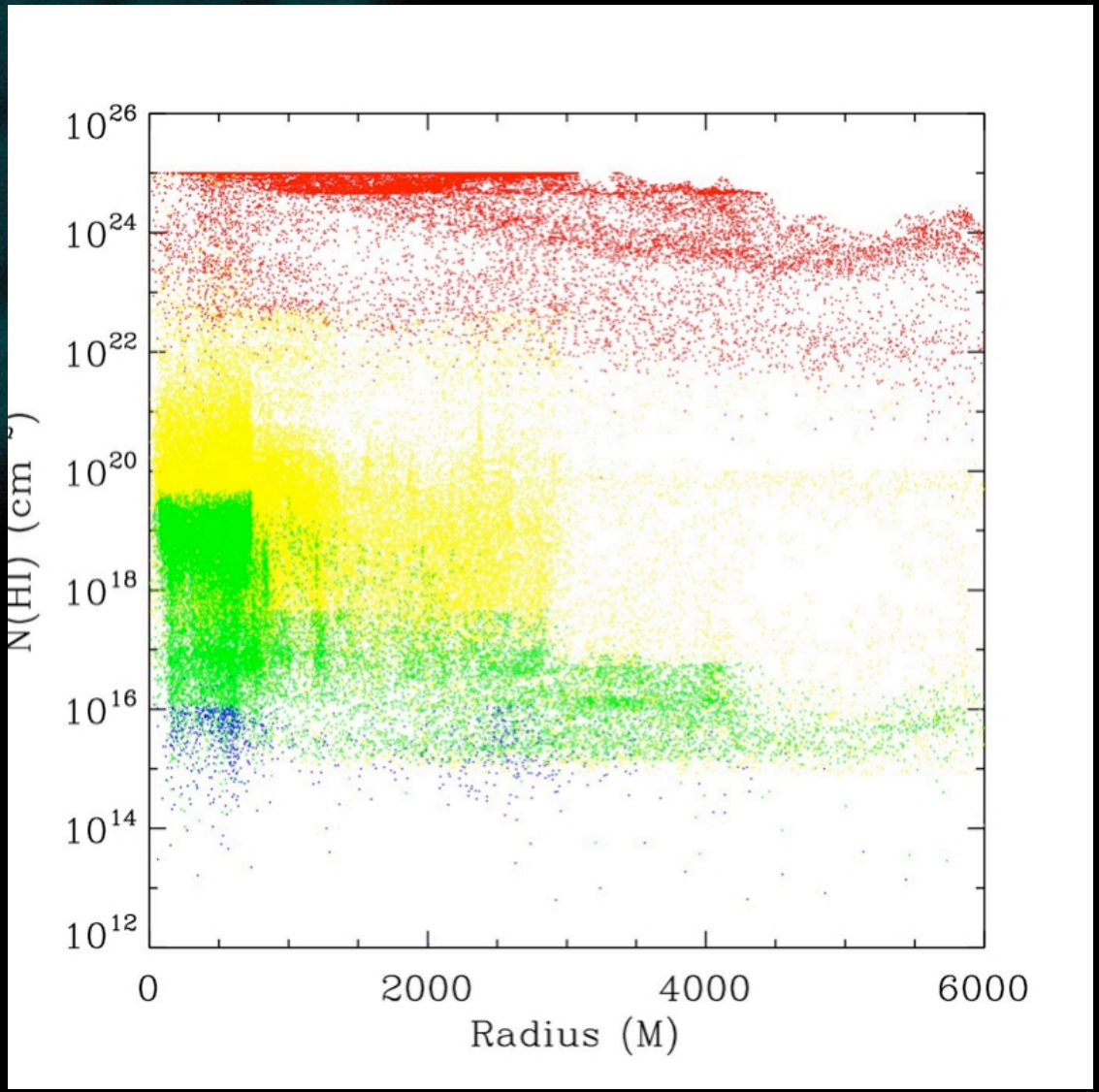


τ(Thomson)

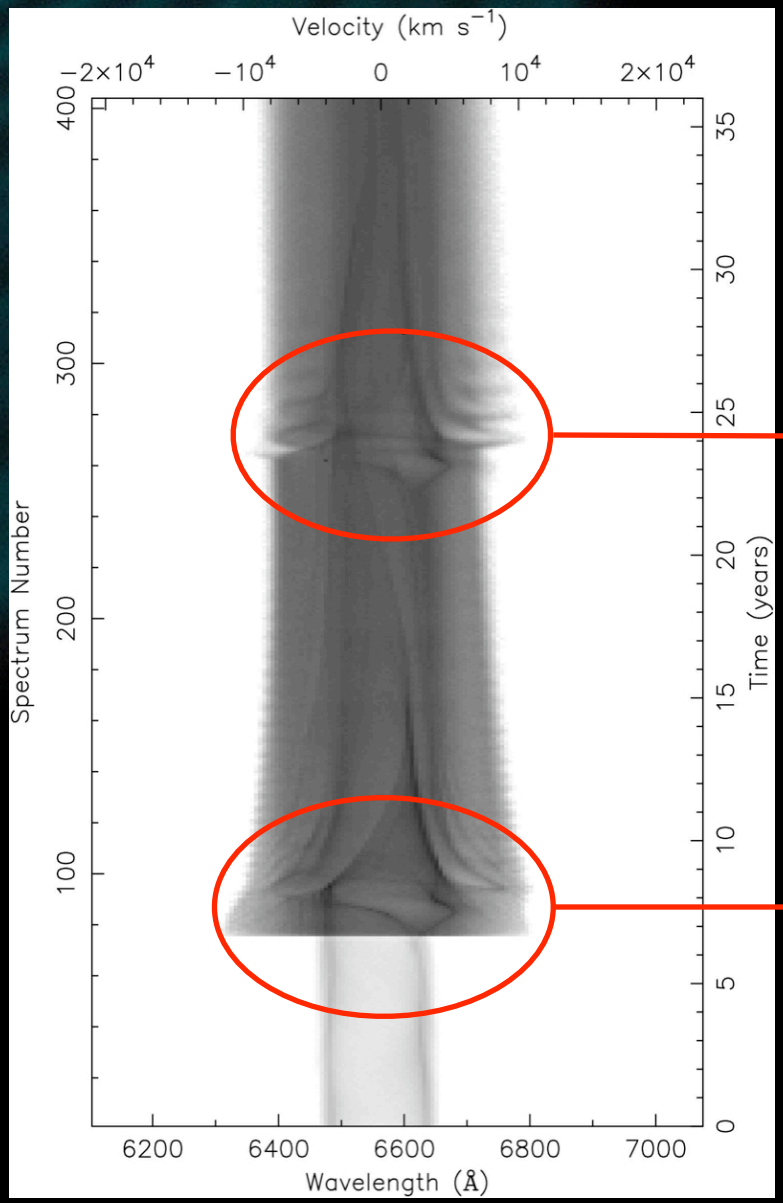


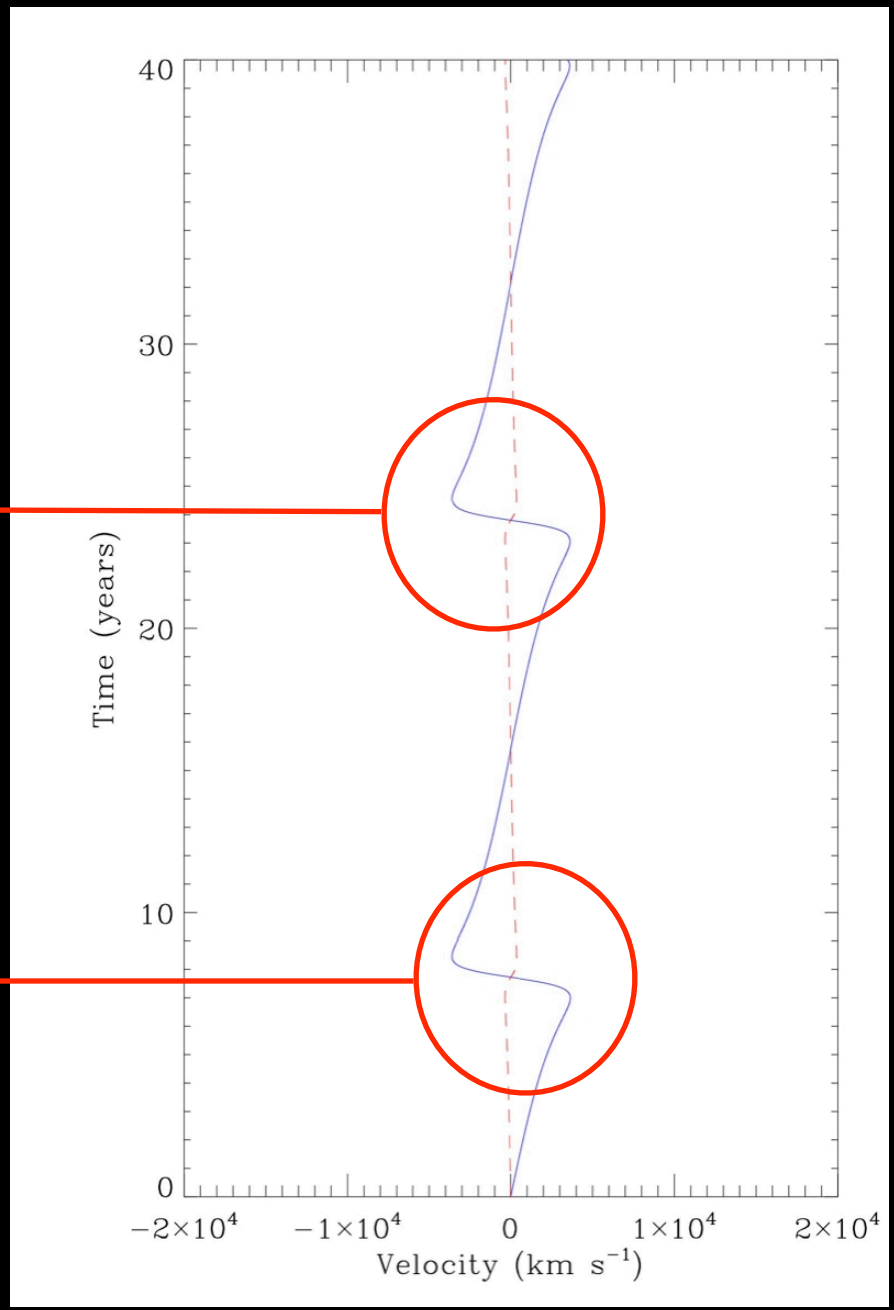
Column density

N(HI)

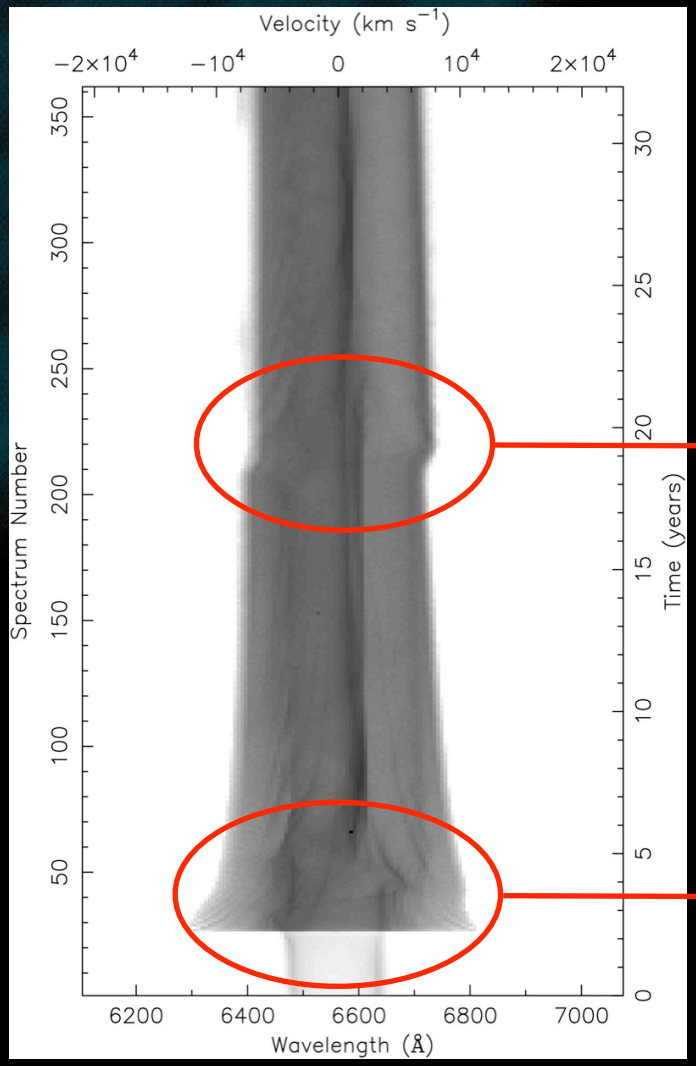


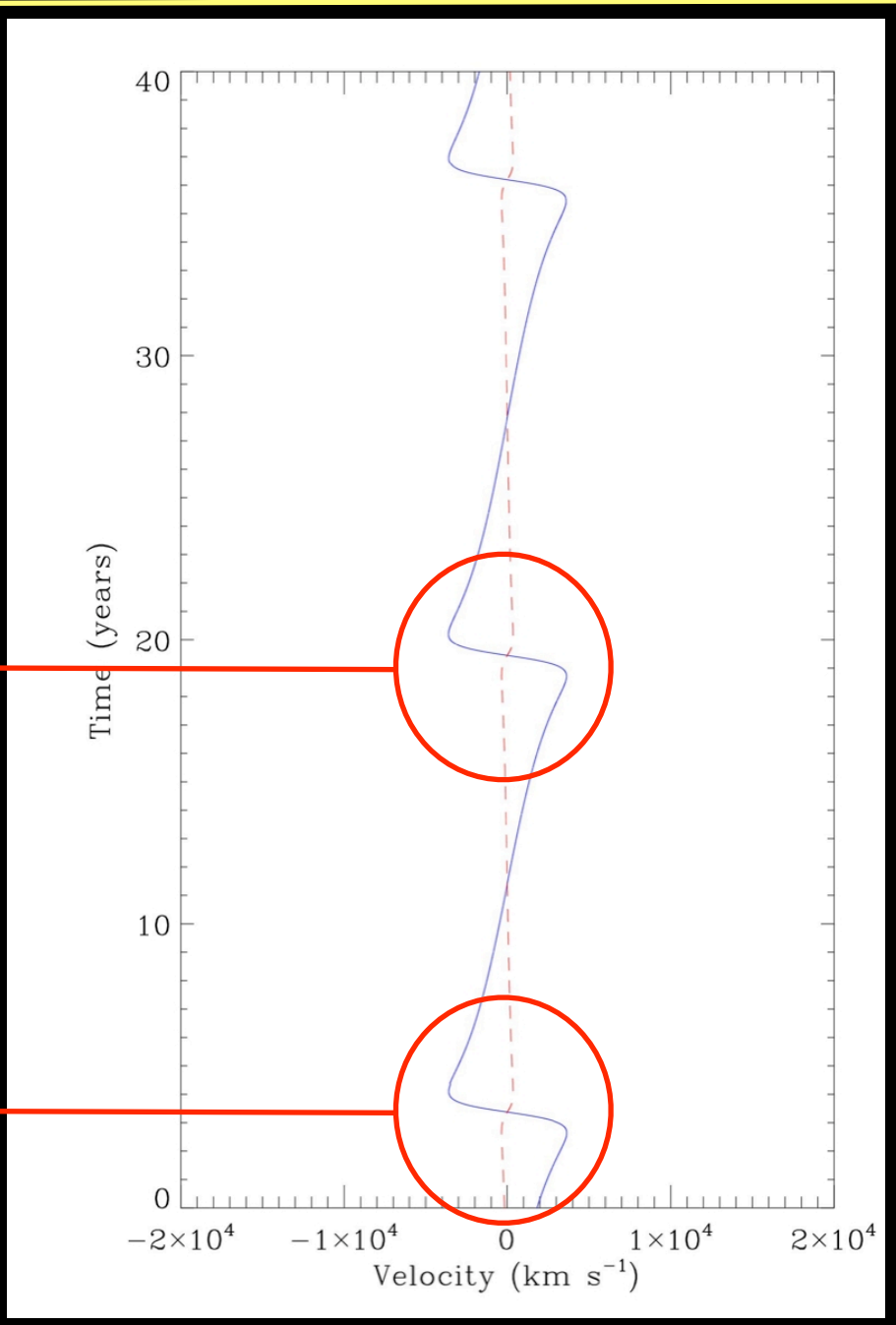
Co-rotating


Velocity (km s^{-1})
−2×10^4
−10^4
0
10^4
2×10^4
Spectrum Number
100
200
300
400
Time (years)
0
5
10
15
20
25
30
35
6200
6400
6600
6800
7000
Wavelength (Å)

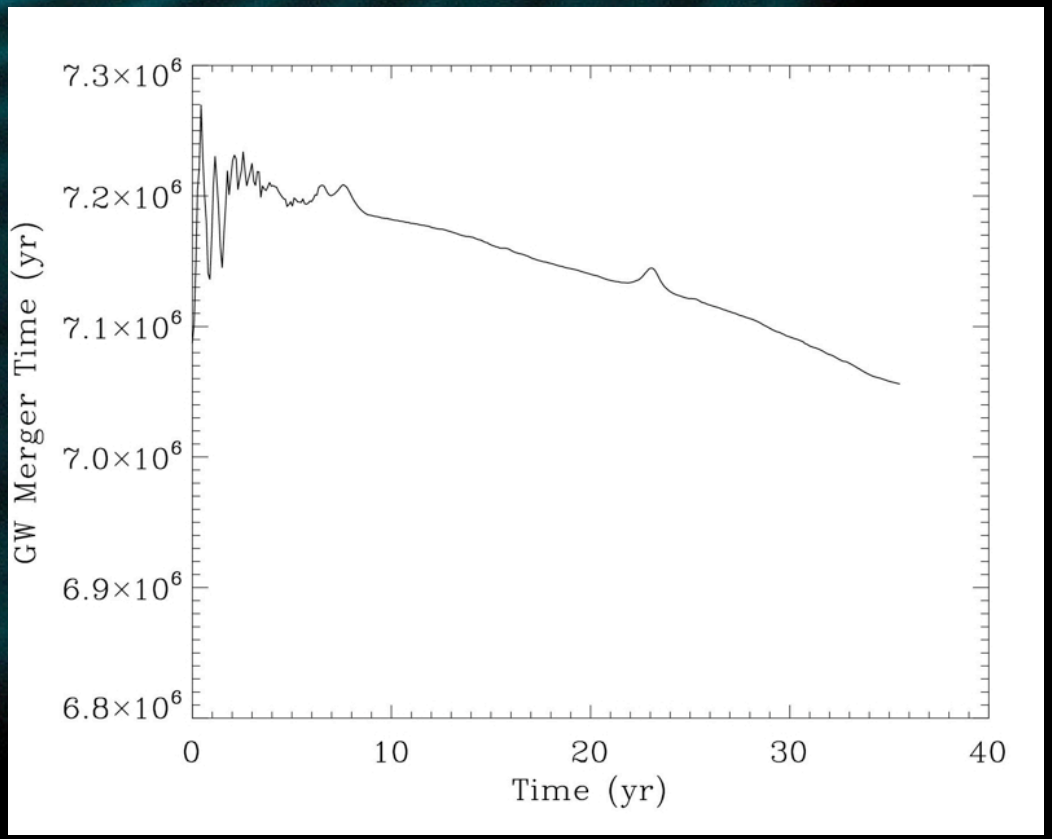

Time (years)
0
10
20
30
40
−2×10^4
−1×10^4
0
1×10^4
2×10^4
Velocity (km s^{-1})

Counter-rotating

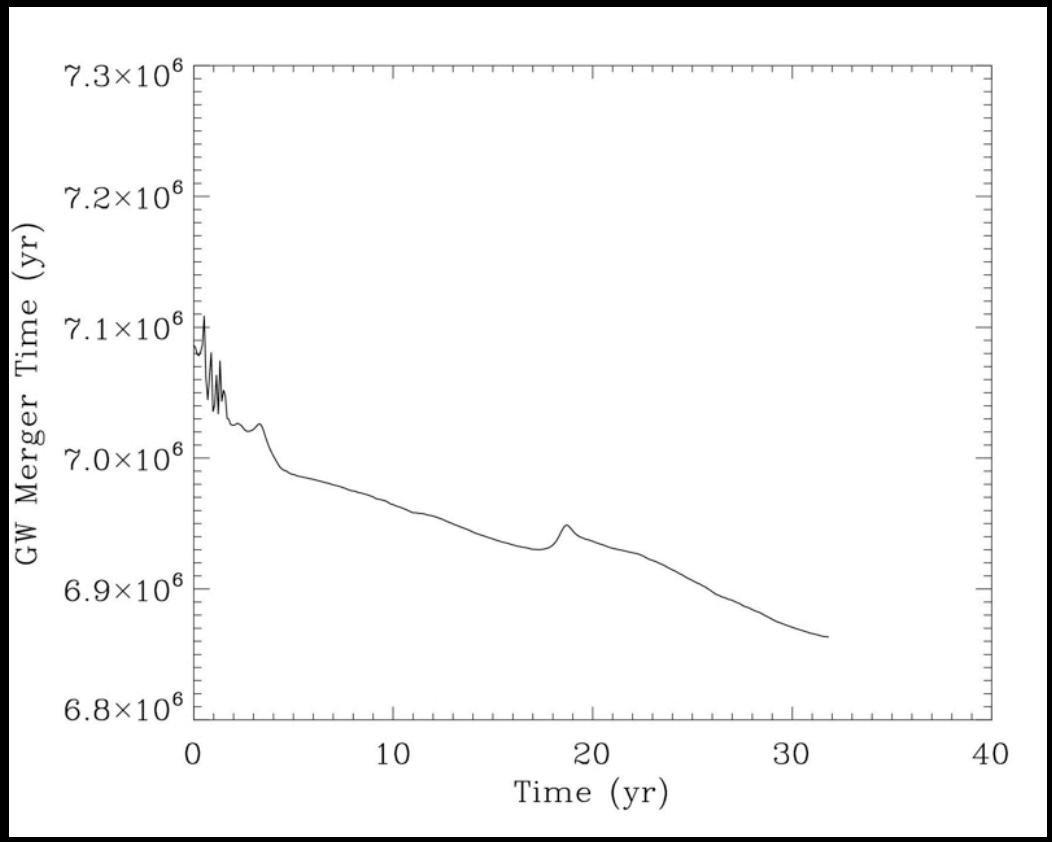




GW merger time scale



Co-rotating



Counter-rotating